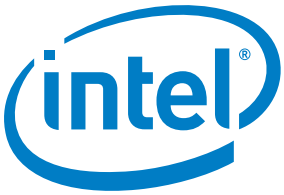

Source Level Debug using OpenOCD/GDB/Eclipse on Intel® Quark SoC X1000

Application Note

March 2014

Order Number: 330015-002US

Contents

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Revision History

Date	Revision	Description
March 2014	002	Added Section 1.2 and Section 4.4.
December 2013	001	Initial release of document.

1 Introduction

This document explains how to use OpenOCD with Eclipse* or GDB* for source level debugging of the Linux* kernel running on the Intel® Quark SoC X1000.

You may see references in the code to product codenames:

- Intel® Quark SoC X1000 (formerly codenamed Clanton)
- Intel® Quark Core (codenamed Lakemont Core)

Note: This document is not a complete guide to source level debugging. It is focused on debugging the Linux* kernel on the Intel® Quark SoC X1000 at source level using OpenOCD with GDB or Eclipse.

1.1 Terminology

Table 1. Terminology

Term	Description
Eclipse	An integrated development environment (IDE) comprising a base workspace and an extensible plug-in system for customizing the environment.
GDB	GNU* Debugger is the standard debugger for the GNU operating system.
JTAG	Joint Test Action Group (JTAG) is the common name for the IEEE 1149.1 Standard Test Access Port and Boundary-Scan Architecture. Debuggers communicate on chips with JTAG to perform operations like single stepping and breakpointing.
OpenOCD	Free and Open On-Chip Debugger.

1.2 References

Table 2. References

Title / Location	Doc ID
Source Level Debug using OpenOCD/GDB/Eclipse on Intel® Quark SoC X1000 https://communities.intel.com/docs/DOC-22203	330015 (this document)
Intel® Quark SoC X1000 Debug Operations User Guide https://communities.intel.com/docs/DOC-22082	329866
Intel® Quark SoC X1000 Datasheet https://communities.intel.com/docs/DOC-21828	329676
OpenOCD User Guide http://openocd.sourceforge.net/doc/html/	N/A
GDB* documentation http://www.gnu.org/software/gdb/documentation/	N/A

Other useful documents about the Intel® Quark SoC X1000 and the Intel® Galileo board may be found at:

https://communities.intel.com/community/makers/documentation

2 Prerequisites

Refer to the Intel® Quark SoC X1000 Board Support Package (BSP) Build Guide and complete the instructions there before attempting the steps outlined in this document.

Required software:

- Linux* host system
- Quark-patched OpenOCD
- GDB
- Eclipse (Indigo tested) with CDT Plugin Installed (Main + Optional Features)
- Quark Kernel compiled with debug symbols
- Git

Required hardware:

- OpenOCD supported JTAG debugger.
  For example:

For a complete set of supporting documentation, please visit the website for your specific JTAG hardware. The board has been tested with the following JTAG debuggers:

- TinCanTools* FLYSWATTER2

  http://www.tincantools.com/wiki/Compiling_OpenOCD

- Olimex* ARM-USB-OCD-H

  https://www.olimex.com/Products/ARM/JTAG/ARM-USB-OCD-H/

The following pin adapter was used to connect the JTAG debugger to the Quark board:

https://www.olimex.com/Products/ARM/JTAG/ARM-JTAG-20-10/

The steps in this document have been validated against an Ubuntu 12.04 LTS 64 bit setup, but should work on any recent Linux distribution with minor adaptations.

3 Setup

3.1 Patching and building OpenOCD

To enable Quark support, you must apply a patch to the OpenOCD source code and then build it. Follow the steps in this section.

Dependencies:

- `git`
- `libtool`
- `automake`

In addition, to use a JTAG pod with an FTDI/FT2232 chip (like the Flyswatter2) you must install the related development library, using a command like:

```
$ sudo apt-get install libftdi-dev
```

Check out the OpenOCD source code, create a branch, and apply the Quark patch using the following commands:

```
$ git clone git://git.code.sf.net/p/openocd/code openocd-code
$ cd openocd-code
```

Configure and build OpenOCD:

```
$ ./bootstrap
$ ./configure --enable-ft2232-libftdi --enable-maintainer-mode
$ make
```

It is not strictly necessary to install OpenOCD. The binary and configuration files can be used from the build/source tree directly if desired. However, it is recommended to perform this additional step:

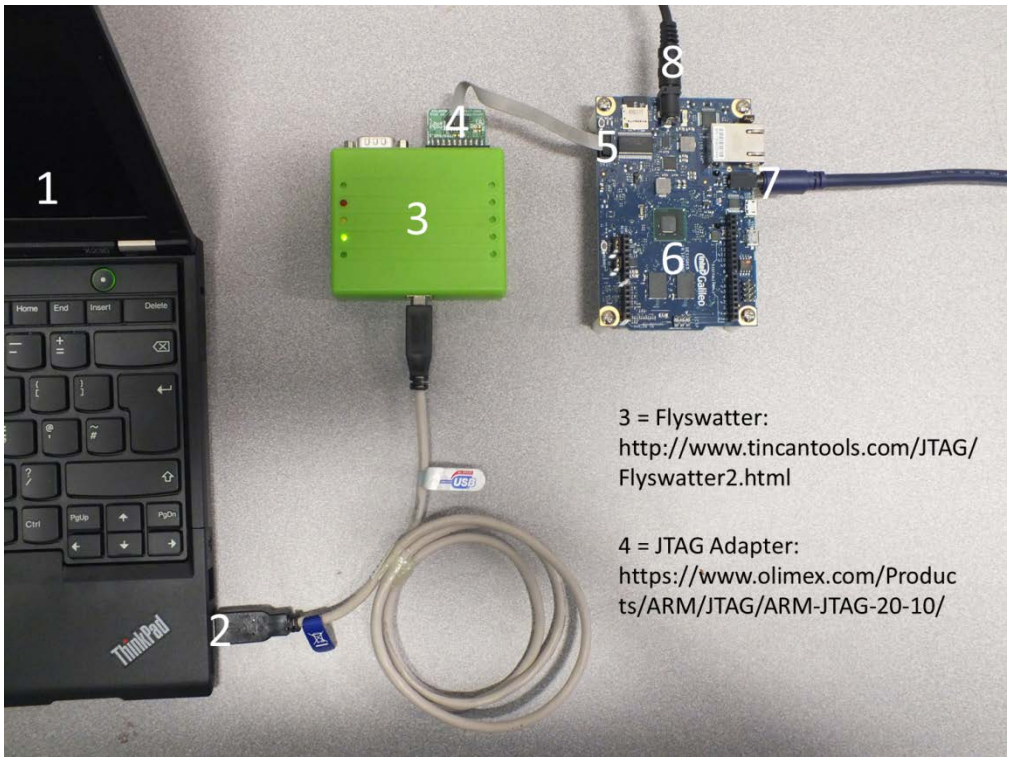
```
$ sudo make install
```

3.2 Debugging Setup

The figure below shows a recommended setup for debugging.

1. Host System running OpenOCD, GDB and Eclipse
2. USB 2.0 male-male A-B cable
3. Flyswatter 2
4. ARM-JTAG-20-10 Adapter
5. JTAG Port
6. Intel® Galileo Board
7. Serial Cable to view boot process
8. Power Supply

Figure 1. Debugging Setup



Note: Flyswatter2 and many JTAG adapters support JTAG and Serial concurrently. If you source a serial cable that connects (7) to (3) as shown above, then you will have JTAG and Serial console data arriving at your host system (1) via USB (2).

3.3 JTAG USB pod access

By default, non-root users won't have access to the JTAG pods connected via USB. You must grant write access to the proper /dev/bus/usb entry every time a device is connected to be able to run OpenOCD using a non-root account.

The process can be automated by adding a udev rule. Simply create a text file in the rules directory:

```
$ sudo vim /etc/udev/rules.d/99-openocd.rules
```

The IDs depend on the JTAG pod. For example, for the Flyswatter2 and the Olimex-ARM-USB-OCD-H, the rules file must have the following content:

```
SUBSYSTEM=="usb", ATTR{idVendor}=="0403", ATTR{idProduct}=="6010",
MODE="0666"
SUBSYSTEM=="usb", ATTR{idVendor}=="15ba", ATTR{idProduct}=="002b",
MODE="0666"
```

3.4 Kernel debug build - Galileo board example

To debug the Linux kernel at source level (for example, using C language sources), you must rebuild the kernel and enable the option to generate debugging information. Next, the newly built kernel and modules have to be installed on the system.

This section describes how to build a debug-enabled kernel for the Galileo board. An SD card is required for this process.

Dependencies:

- `git`
- `texinfo`
- `gawk`
- `diffstat`
- `chrpath`

Note: Building the kernel and the system for the SPI flash is not covered in this example.

1. Get the Quark Board Support Package (BSP) software

   In this document, `<version>` is used as a placeholder string for the BSP software version.

   Download the latest BSP package (`Board_Support_Package_Sources_for_Intel_Quark_<version>.7z`) and unpack it. It contains several archives. You will use two of them in the steps below:

   ```
   meta-clanton_<version>.tar.gz
   clanton_linux_<version>.tar.gz
   ```

2. Build `image-full` and create a bootable SD card

   You can skip this step if you have already built the `image-full` and have set up an SD card using the steps described in the Quark BSP Build Guide. In the steps

that follow, you must reference the toolchain that you built previously (that is, to set the correct environment variables).

Create a working directory of your choice to build the BSP and go there:

```
$ cd /PATH/TO/MY_BSP_WORK_DIR
$ tar zxf meta-clanton_<version>.tar.gz
$ cd meta-clanton_<version>
$ ./setup.sh -e meta-clanton-galileo
$ . poky/oe-init-build-env yocto_build
$ bitbake image-full
```

The step above can take as long as several hours, because all packages need to be fetched from the internet and then built. If you have already downloaded all the files previously (they will be stored in `yocto_build/downloads`), you can execute a build without doing sanity checks on the network to save time. Disable sanity checks by adding this line in the `yocto_build/conf/local.conf file`: `CONNECTIVITY_CHECK_URIS = ""`

At the end of the build, a message similar to this will be displayed:

```
NOTE: Tasks Summary: Attempted 1209 tasks of which 269 didn't need to
be rerun and all succeeded.
```

After the image build is completed successfully, you must copy the files below to the root of the SD card to be able to boot the system on the Galileo board:

- `image-full-clanton.ext3`
- `core-image-minimal-initramfs-clanton.cpio.gz`
- `grub.efi`
- `boot (directory)`

The files can be found in:

```
/PATH/TO/MY_BSP_WORK_DIR/meta-
clanton_<version>/yocto_build/tmp/deploy/images/
```

To make a fully bootable SD card, the kernel file itself (`bzImage`), must be copied as well. The kernel file produced by the BSP build does not contain debug information and **cannot** be used for source level debugging. The following steps will create a proper kernel file.

3. Get the kernel

   Open a new shell. (The shell used for the BSP build of the previous steps contains changes to the environment which are no longer needed.)

   Create a new directory of your choice to rebuild the kernel and go there:

   ```
   $ cd /PATH/TO/MY_KERNEL_BUILD_DIR
   $ tar zxf clanton_linux_<version>.tar.gz
   $ cd clanton_linux_<version>
   ```

   Note: Before entering the next command, make sure you have `git` configured with a username and email (can be false values) otherwise the command will fail. For details, use the command `man git-config`.

   ```
   $ ./gitsetup.py
   ```

   The command above fetches the proper kernel version from the internet and patches it with the appropriate Quark changes.

4. Specify the correct toolchain

   Export binaries of the toolchain built in step 2 to your $PATH as follows:

   ```
   export PATH=/PATH/TO/MY_BSP_WORK_DIR/meta-clanton_<version>/yocto_build/tmp/sysroots/x86_64-linux/usr/bin/i586-poky-linux-uclibc:$PATH
   ```

   Also, all make commands that deal with the kernel must be specified using the proper architecture (ARCH) and crosscompiler (CROSS_COMPILE) switches as described below.

5. Configure and build the kernel

   Starting from the directory created in step 3 above, select the proper kernel configuration and enable debug information generation.

   ```
   $ cd /PATH/TO/MY_KERNEL_BUILD_DIR
   $ cd clanton_linux_<version>
   $ cd work
   $ cp meta/cfg/kernel-cache/bsp/clanton/clanton.cfg .config
   $ ARCH=i386 CROSS_COMPILE=i586-poky-linux-uclibc- make menuconfig
   ```

   The kernel configuration screen is launched. Go to the General setup group and find the Local version item. Edit it with the following content:

   ```
   -yocto-standard
   ```

   Go back to the initial menu by clicking su Exit and go to the Kernel hacking group. Scroll down the list and find Compile the kernel with debug info, and enable it (when enabled, [*] will be shown). You can now optionally choose any other desired kernel options, then exit and confirm saving the configuration.

   Create a file using:

   ```
   $ touch .scmversion
   ```

   Issue the command below to build the kernel:

   ```
   $ ARCH=i386 CROSS_COMPILE=i586-poky-linux-uclibc- make
   ```

   If you have a multicore machine, add the -jN switch to the make command to speed up the build.

   If the build is successful, the message below is displayed:

   ```
   Kernel: arch/x86/boot/bzImage is ready  (#1)
   ```

   This bzImage file must be copied to the root of your SD card. Once copied, the Galileo board fully boots Yocto Linux and the kernel can be debugged at source level.

6. OPTIONAL – build kernel module “out-of-tree” and generate all output in a separate directory.

   You must modify KDIR in the module Makefile to look like:

   ```
   KDIR := /PATH/TO/MY_KERNEL_BUILD_DIR/clanton_linux_<version>/work
   ```

   Open a new shell, source the PATH, and use the proper ARCH and CROSS_COMPILER switches:

   ```
   $ cd /PATH/TO/MY_MODULE
   $ export PATH=/PATH/TO/MY_BSP_WORK_DIR/meta-
   clanton_<version>/yocto_build/tmp/sysroots/x86_64-linux/usr/bin/i586-
   poky-linux-uclibc:$PATH
   $ ARCH=i386 CROSS_COMPILE=i586-poky-linux-uclibc- make
   ```

3.5 Modifying bootloader

To make debugging easier around the kernel idle function, it is recommended to add the idle=poll parameter in the bootloader entry corresponding to the kernel that is being debugged. The screenshot below shows a typical /boot/grub/grub.conf file.

```
24 title IVA 0.8.0 - idle poll full
25     root (hd0,0)
26     kernel /bzImage root=/dev/ram0 console=ttyS1,115200n8
   earlycon=uart8250,mmio32,0x8010f000,115200n8 reboot=efi,warm apic=debug rw LABEL=boot
   debugshell=5 idle=poll
27     initrd /core-image-minimal-initramfs.cpio.gz
```

This file can be edited directly on the SD card for a Galileo board.

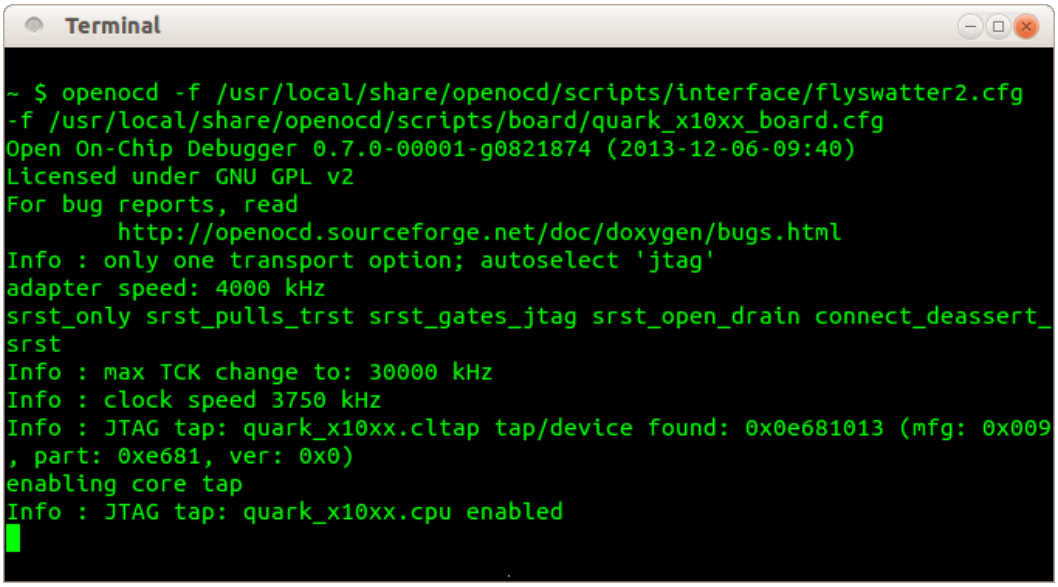
If this modification is not added, you cannot assembly-step away or set hardware breakpoint and watchpoints when sitting on a HLT instruction. However, software breakpoints and high level source stepping using software breakpoints will work.

4 Debugging

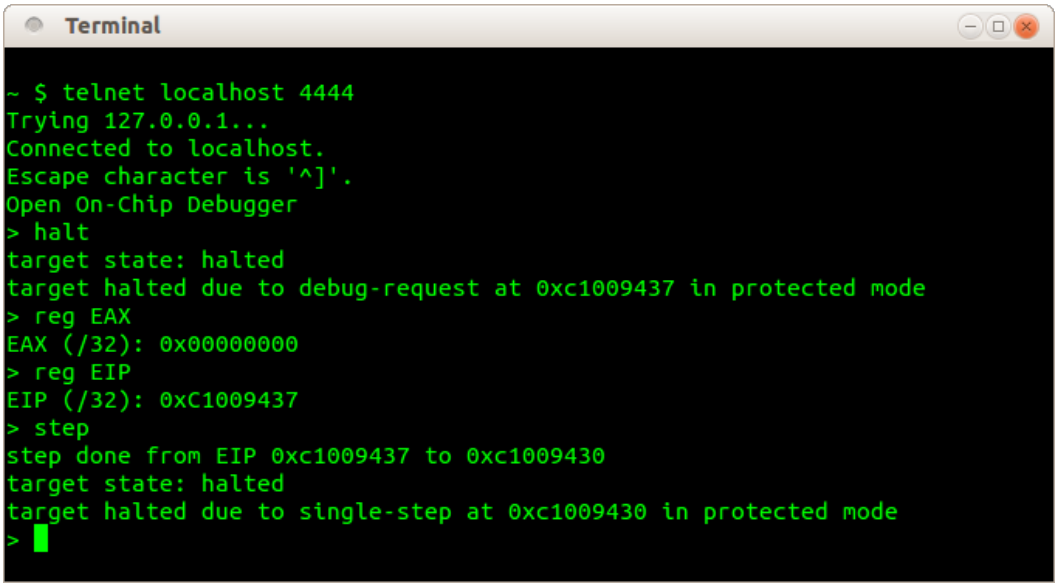
4.1 OpenOCD

The first step to enable source level debug is to connect your JTAG pod to the board and run OpenOCD selecting the correct interface and board configuration files. The example below uses a Flyswatter2 JTAG debugger.

```
openocd -f interface/flyswatter2.cfg -f board/quark_x10xx_board.cfg
```



It is possible to use OpenOCD as a standalone tool for basic debugging. You can connect to the OpenOCD session using telnet on port 4444 and issue commands (this step is not required for source level debug). This can be seen in the following screenshot.



Enter `help` in the telnet console to return a list of available commands and their description. For complete details, see the OpenOCD user guide here:

http://openocd.sourceforge.net/doc/html/

Even if you are in GDB, you can still run OpenOCD commands by prefixing the command name with the GDB `monitor` command. For example, to halt the core CPU from the GDB command line, issue the `monitor halt` command. To resume the core CPU, issue the `monitor resume` command.

4.2 GDB

GDB documentation is available here:

http://www.gnu.org/software/gdb/documentation/

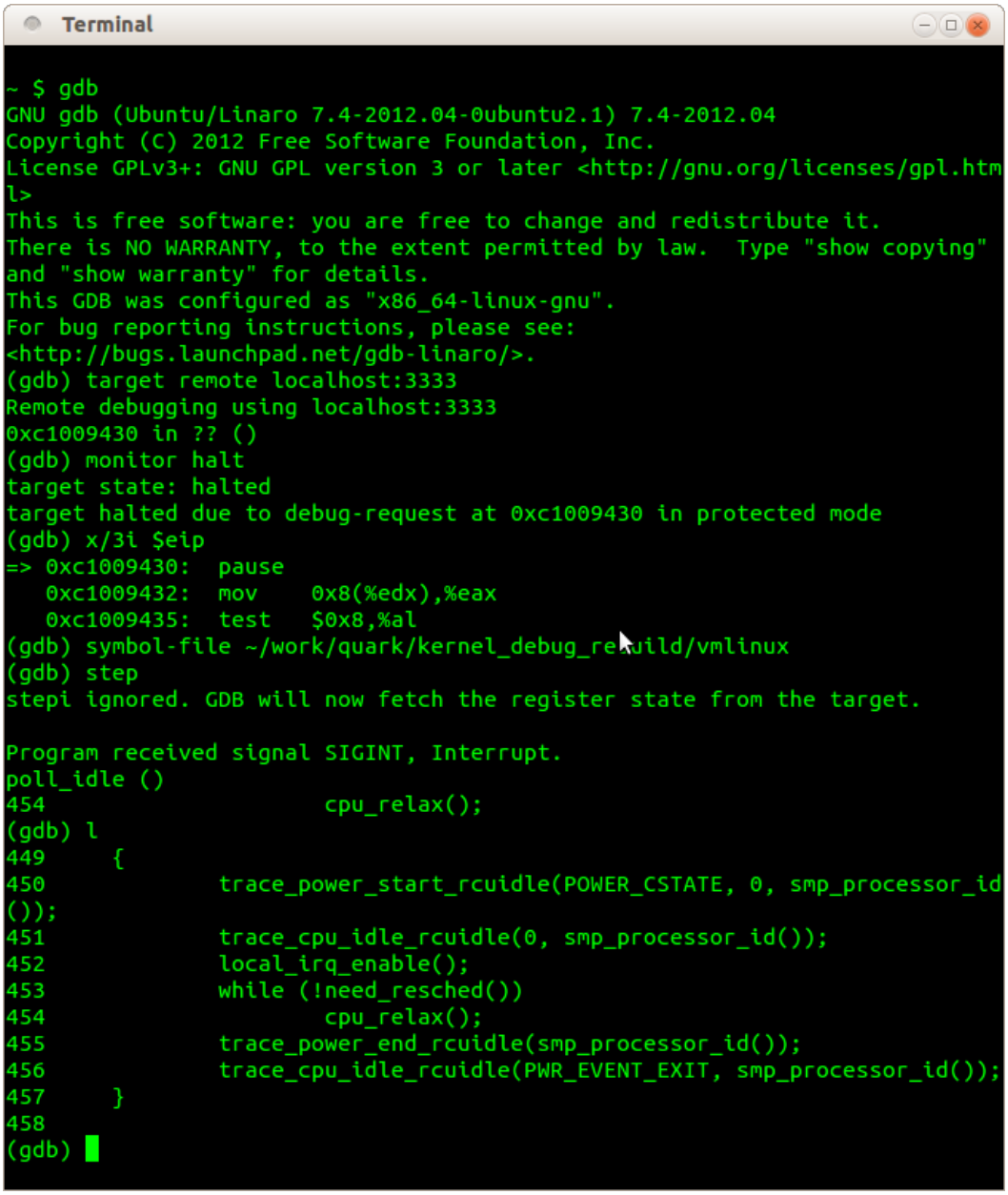
It is possible to perform source level debug using GDB by connecting to the OpenOCD internal GDB server, which answers on port 3333 by default. OpenOCD must be running as shown in the previous section.

Run GDB and connect to the OpenOCD internal GDB server. Load the debug info of a debug compiled Quark Kernel vmlinux file.

For the kernel built in Section 3.4, the commands are:

```
$ gdb
(gdb) target remote localhost:3333
(gdb) monitor halt
(gdb) symbol-file
/PATH/TO/MY_KERNEL_BUILD_DIR/clanton_linux_<version>/work /vmlinux
```

The screenshot below shows these steps in operation. After they are completed, the board is ready to be source level debugged using GDB.



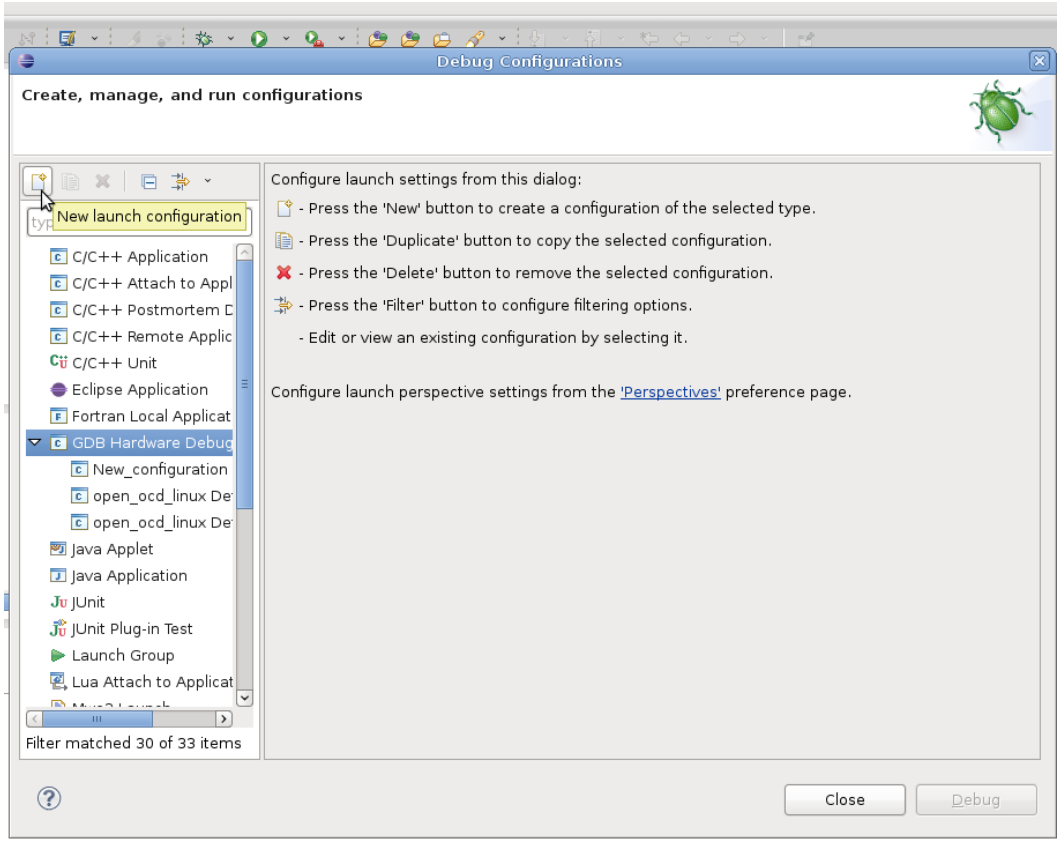
Note: Even if you are in GDB, you can still run OpenOCD commands by prefixing the command name with the GDB `monitor` command as shown in the screenshot. Use the command `monitor help` to see if OpenOCD supports a particular command. For example, `monitor mdw phys` allows the physical memory to be read.

4.3 Eclipse

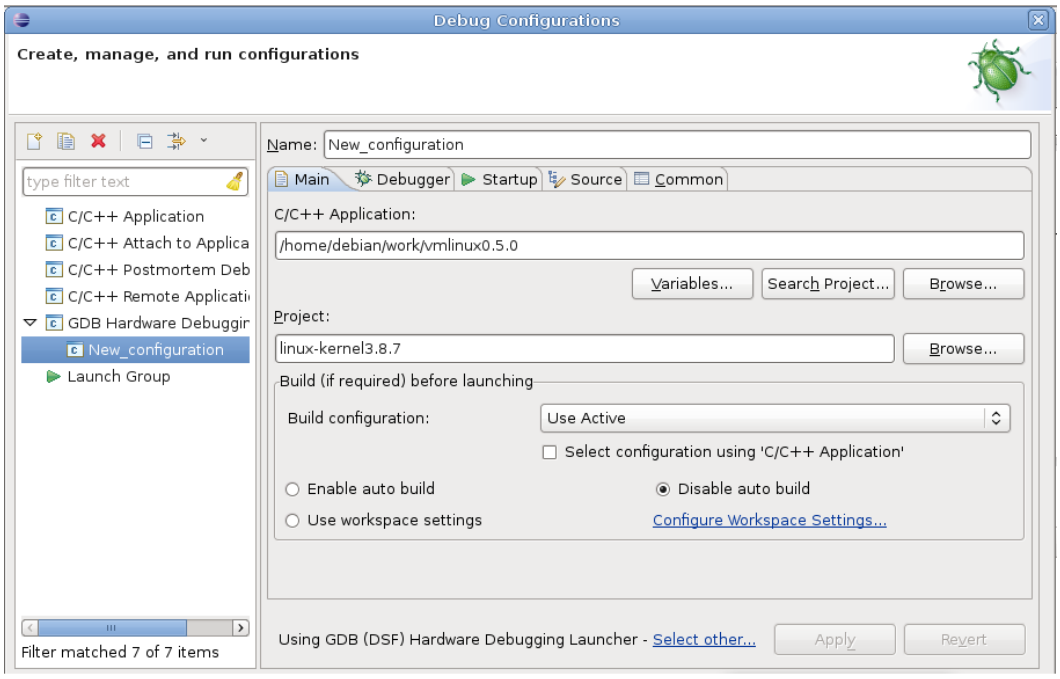
It is also possible to perform source level debug using Eclipse with the C/C++ GDB Hardware Debugger plug-in. The following configuration is required to enable source level debugging of the board in the Eclipse environment.

Install the C/C++ GDB Hardware Debugging plug-in, if missing, using the standard Install Software from the Eclipse Help menu.

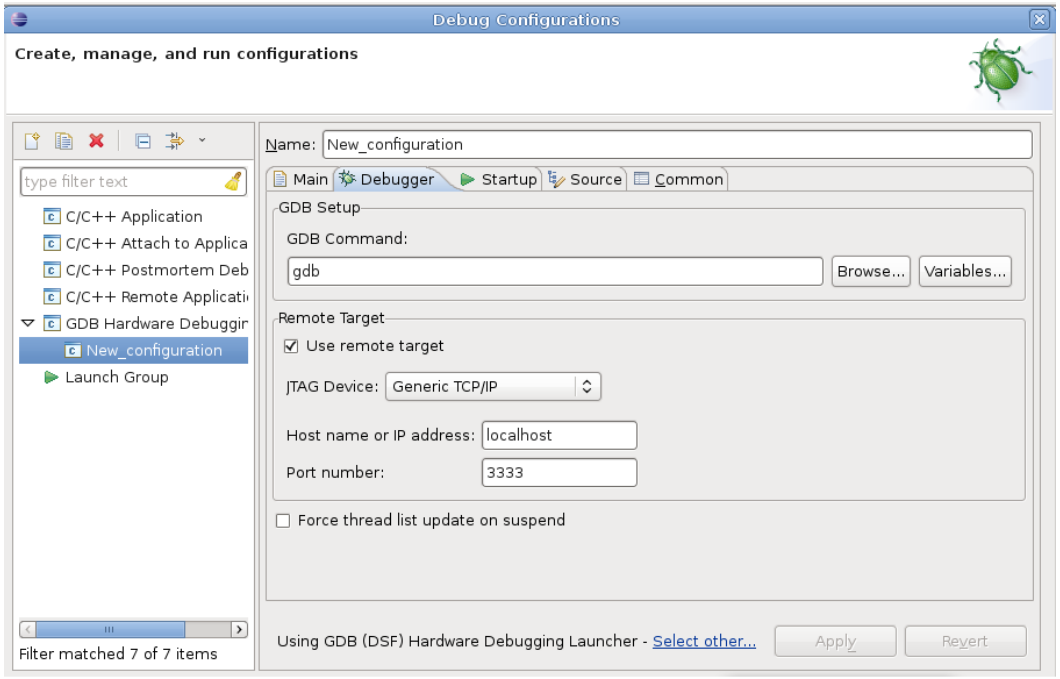
Create a new project and switch to the C/C++ perspective. From the **Run** menu, open the **Debug Configurations** dialog, and add a new launch configuration under GDB hardware debugging, as shown below.



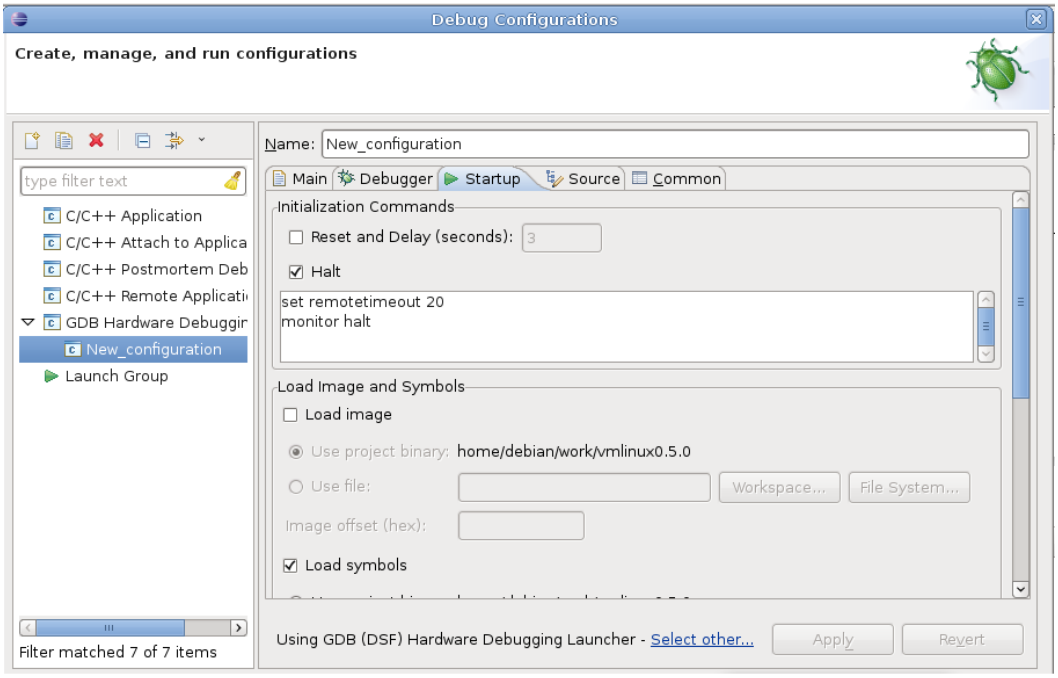
Set application to the debug symbol enabled vmlinux kernel file.



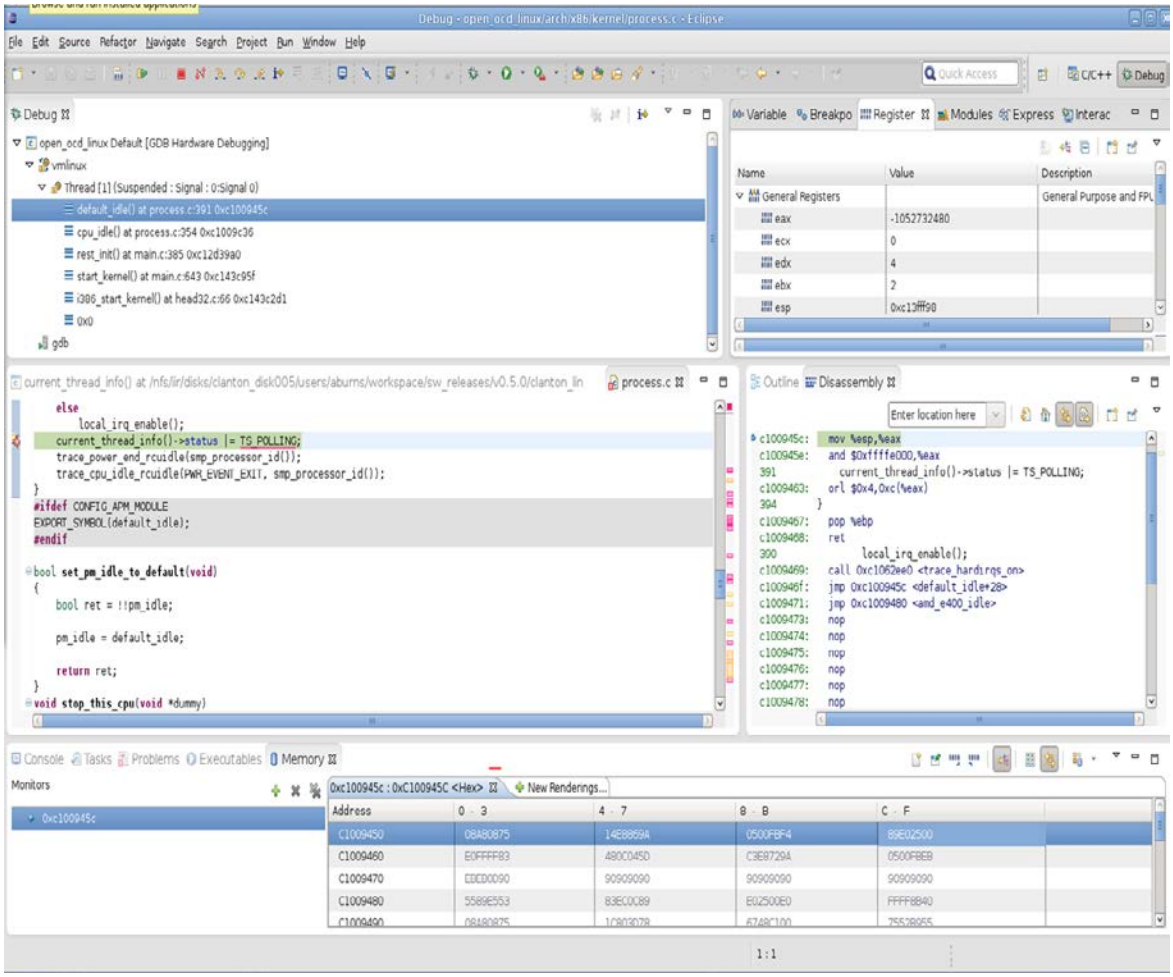
Enable **Use remote target** and set the host name and port number.



Select **Halt** and add the commands: **set remotetimeout 20** and **monitor halt**.



Eclipse is now set up to perform source level debug on the board as shown below. Note it is still necessary to first launch OpenOCD in a separate shell, as described in Section 4.1.



4.4 GDB and kernel modules

Debugging Linux kernel modules requires additional steps. The load address of the module's different sections is chosen by the kernel at runtime and thus it is necessary to find out this information and pass it over to GDB.

In this section, an example kernel module built "out-of-tree" (generating all output in a separate directory) is used to show the debugging approach.

For additional information, see
https://www.kernel.org/doc/Documentation/kbuild/modules.txt

1. Create a new directory where the module files will be stored.
   In this example, it is called `simple_timer`
   ```
   $ mkdir simple_timer
   ```

2. In this directory, create a file named `Makefile` having the following content:
   ```
   obj-m := simple_timer.o
   ```

```
ccflags-y := -g -O0
KDIR := /opt/galileo/meta-
clanton_<version>/yocto_build/tmp/work/clanton-poky-linux-
uclibc/linux-yocto-clanton/3.8-r0/linux-clanton-standard-build
all:
    $(MAKE) -C $(KDIR) M=$(PWD) modules
clean:
    $(MAKE) -C $(KDIR) M=$(PWD) clean
```

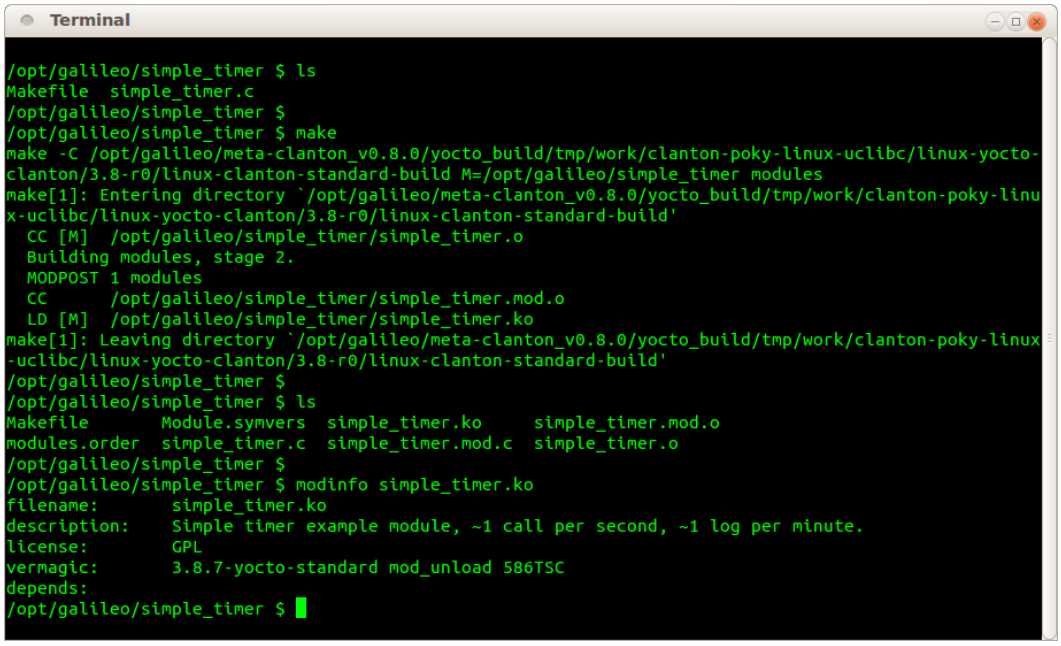
3. Modify KDIR to point to the actual kernel build directory, as shown in Section 3.4 of this document.
4. Create the actual module and name the file `simple_timer.c` having this content:

```
#include <linux/kernel.h>
#include <linux/module.h>
#include <linux/timer.h>
#include <linux/jiffies.h>
MODULE_DESCRIPTION("Simple timer example module, ~1 call per second,
~1 log per minute.");
MODULE_LICENSE("GPL");
static struct timer_list simple_timer;
static unsigned long times_called;
static void simple_timer_function(unsigned long ptr)
{
    unsigned long minutes;
    times_called++;
    minutes = times_called / 60;
    if(times_called % 60 == 0)
        printk(KERN_INFO "simple_timer: ~%ld minute(s) and counting\n",
            minutes);
    mod_timer(&simple_timer, jiffies + HZ);
}
static int __init simple_timer_init(void)
{
    printk(KERN_INFO "simple_timer: loading - %d HZ\n", HZ);
    times_called = 0;
    init_timer(&simple_timer);
    simple_timer.function = simple_timer_function;
    simple_timer.expires = jiffies + HZ;
    add_timer(&simple_timer);
    return 0;
}
static void __exit simple_timer_exit(void)
{
    printk(KERN_INFO "simple_timer: unloading\n");
    del_timer(&simple_timer);
}
module_init(simple_timer_init)
module_exit(simple_timer_exit)
```

This example module sets up a kernel timer that expires and is set again roughly every second by calling the `simple_timer` function. In addition, every minute a new info kernel message will be logged. This type of message can be examined in several ways depending on the kernel settings: using the `dmesg` command, logged to files, or appearing directly on the console (as with the Galileo board).

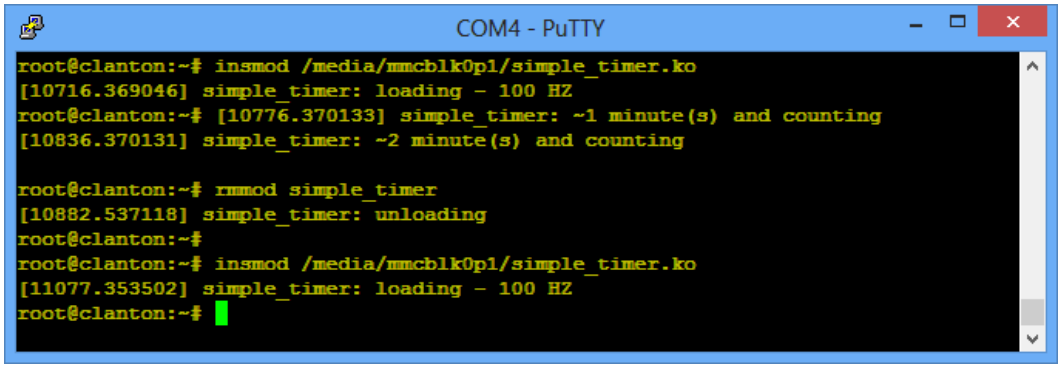
5. To build the module, the path to the cross-compile toolchain has to be in the path, as shown in Section 3.4, and the `make` command has to be invoked as shown in the screenshot below.

   A few files are produced and `simple_timer.ko` is the kernel module itself.

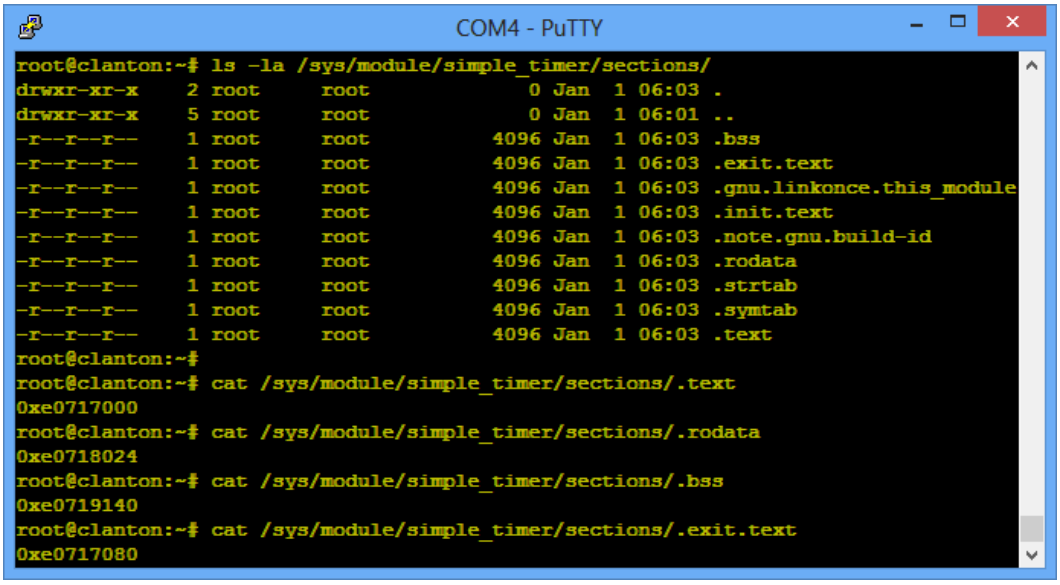


   The module can now be copied to the target system.

6. For a Galileo board, copy the file to the SD card and insert it onto the board. After the board is booted, the SD card is mounted automatically under `/media` and the kernel module can be inserted and removed as shown below, where the terminal program is connected to the Quark board serial port:



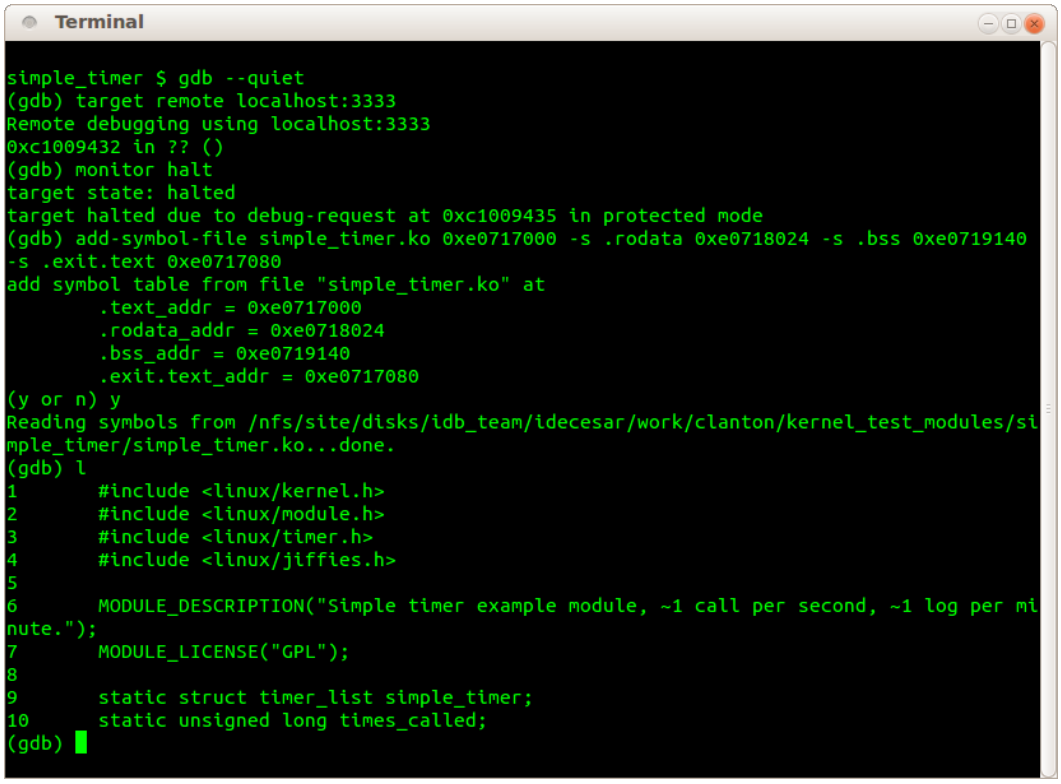
7. After the module is loaded, the corresponding `/sys/module` entry on the board can be queried as shown below:



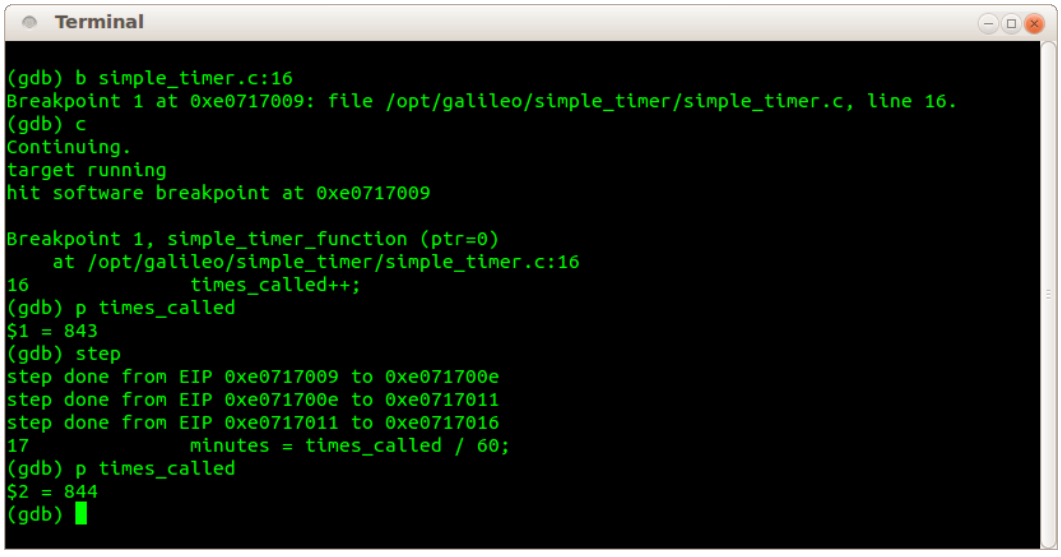
The address of `.text` and the other relevant sections are now known and can be passed to the `add-symbol-file` GDB command when loading the debug information for the module.

The `.text` address is the first, mandatory parameter, the other sections are optional and can be specified using the `–s` switch. The command for loading the debug information of the module in gdb is:

```
(gdb) add-symbol-file simple_timer.ko 0xe0717000 –s .rodata
0xe0718024 –s .bss 0xe0719140 –s .exit.text 0xe0717080
```



The setup is complete and the kernel module can be source-level debugged.



Note: If the module is unloaded and then loaded, the section addresses must be checked again. Typically the addresses are different each time.

§